Stars & galaxies, example class 3

Question 1.

1. 1) From observations of the X-ray gas, assuming hydrostatic equilibrium, (2) from galaxy motions, assuming virial equilibrium
2. Assume that the ratio dark matter/gas in cluster is universal value. Get the mean baryon density from Deuterium abundance and Big Bang nucleo-synthesis. Combine these to get mean dark matter density.
3. TF relates luminosity L with circular velocity V_c of spiral galaxy, $L = \alpha V_c^4$. To use as standard candle: first determine α from nearby spirals with known distance. For spiral with unknown distance: measure V_c, use relation to get L, from apparent magnitude then determine distance.

Question 2.

1) The 3D velocity dispersion $\sigma = 3^{1/2}\,\sigma_{1D}$ (assuming isotropy). Virial theorem, Eq. (9.4), then gives $M = R\sigma^2/G = 1.5 \times 10^{15} M_\odot$.

2) Eq. (9.7) gives $T = (2/3)(\mu m_p/k_B)\,(GM/R) = 8.75 \times 10^7$K=7.54 keV, for $\mu = 0.5$. Temperature is much higher than H binding energy, hence fully ionised, hence $\mu = 0.5$ for hydrogen gas.

3) Total gas mass $M_g = M/7 = 2.16 \times 10^{14} M_\odot$, mean electron density $n_e = M_g/(4\pi\, R^3 m_p/3) = 0.77 \times 10^{-4}$ electrons per cm^3.

4) $L_x = 1.42 \times 10^{-27} n_e^2 T^{1/2}\,(4\pi R^3/3) = 2.64 \times 10^{44}$ erg s^{-1}.

5) Energy of 1 photon $E_x = 10$ keV $= 1.6 \times 10^{-8}$ erg, hence total photon flux is $N_x = L_x/E_x$. Count rate in Chandra $= C = N_x * (S/4\pi d^2) = 13.6$ photons per second.

6) Metal mass $M_z = Z_\odot \times M_g/3 = 1.44 \times 10^{12} M_\odot$, where $Z_\odot = 0.02$ is the metal abundance of the Sun (e.g. page 95, footnote 3). For yield $y = 0.02$, mass once in stars, $M_\star = M_z/y = Z_\odot M_g/3/y = M_g/3 = 7.20 \times 10^{13} M_\odot$,*i.e.* 1/3 of the total gas mass.

7) Number of SNe $N = M_\star/100 M_\odot = 7.20 \times 10^{11}$, currently $N/t_0 = 55$ per year.

8) Total SN energy is $E_{\rm SN} = N \times 10^{51}$ erg$=7.20 \times 10^{62}$ erg. Thermal energy of gas per unit mass is $u = (3/2)(k_{\rm B}T/\mu m_{\rm h}) = (GM/R)$. Hence total thermal energy is $U = u\,M_g = 9.31 \times 10^{63}$ erg, hence $E_{\rm SN}/U = 7.7\%$, so SNe may have had a small effect on heating the gas.